Research Note

No. 114 1994

ISSN 0226-9368

Use of Site Factors To Predict Lodgepole Pine and Interior Spruce Site Index in the Sub-Boreal Spruce Zone

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Ministry of Forests

103-06915/

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Ministry of Forests
Research Program

1994

Canadian Cataloguing in Publication Data
Main entry under title:
Use of site factors to predict lodgepole pine and interior spruce site index in the sub-boreal spruce zone

(Research note; ISSN 0226-9368 ; no. 114)

Includes bibliographical references: p.
ISBN 0-7726-2000-8

1. Site index (Forestry) - British Columbia - Prince Rupert Region. 2. Lodgepole pine - British Columbia - Prince Rupert Region - Growth. 3. Spruce - British Columbia - Prince Rupert Region - Growth. 4. Forest ecology - British Columbia - Prince Rupert Region. 5. Bioclimatology - British Columbia - Prince Rupert Region. 6. Prince Rupert Forest Region (B.C.). I. Wang, G. (Gang), 1964- II. British Columbia Ministry of Forests. III. Series: Research note (British Columbia. Ministry of Forests) ; no. 114.

SD387.E58U85 1994 634.9'75'09711 C94-960016-4

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1994 Province of British Columbia
Published by the
Research Branch
Ministry of Forests
31 Bastion Square
Victoria, B.C. V8W 3E7

Copies of this and other Ministry of Forests titles are available from Crown Publications Inc., 546 Yates Street, Victoria, B.C. V8W 1K8.

SUMMARY

To establish a link between ecological site quality and forest productivity in the Sub-Boreal Spruce zone of the Prince Rupert Forest Region, site index and site data from 93 lodgepole pine stands and 77 interior spruce stands were obtained and analyzed. The stands studied were distributed across 2 climatic regimes (biogeoclimatic subzones), 8 soil moisture regimes, and 5 soil nutrient regimes. These regimes were used as categorical variables to stratify the stands and in the regression analysis. Some combinations of soil moisture and nutrient regimes were poorly represented.

Site index of lodgepole pine and interior spruce changed with soil moisture and nutrient regimes, but not with climate. The pattern of change in site index in relation to soil moisture was similar for both species, but differed in relation to soil nutrients. Site index of interior spruce was significantly lower than that for lodgepole pine on nutrient-deficient sites. Of the six types of regression models developed, the edatope model showed strong relationships between site index and soil moisture and nutrient regimes (R^2 >0.80, SEE <1.6 m) for both lodgepole pine and interior spruce. This model was used to draft site index isolines which were then superimposed onto edatopic grids. Estimates of soil moisture and soil nutrient regimes were found to be good predictors of lodgepole pine and interior spruce site index over a large area. Additional sampling of sites that were poorly represented and testing against independent data sets are recommended.

ACKNOWLEDGEMENTS

We thank J. Pojar (Prince Rupert Forest Region) for assistance in locating the study plots and B.A. Blackwell and K.J. Haberl (B.A. Blackwell and Associates Ltd.) for collecting field data. A. Banner, R. Green, and A. MacKinnon (B.C. Ministry of Forests), P. Marshall (University of British Columbia), and J. Thrower (J.S. Thrower & Associates Ltd.) gave valuable comments in reviewing the manuscript. Funding for the study was provided through the G.F. Dodd Operational Research Chair, B.C. Ministry of Forests, Prince Rupert Forest Region. This support is gratefully acknowledged.

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INTRODUCTION

In British Columbia, biogeoclimatic ecosystem classification is widely used to recognize different types of forest ecosystems according to the ecological quality of their sites. With the classification system in place, silvicultural management has been given a solid ecological foundation; however, relationships between forest growth and ecological site quality have not yet been fully developed. The purpose of this study was to determine how site conditions within the Sub-Boreal Spruce zone of the Prince Rupert Forest Region affect the height growth of lodgepole pine (*Pinus contorta* Dougl. *ex* Loud.) and interior spruce (*Picea engelmannii* Parry *ex* Engelmann x *P. glauca* [Moench] Voss).

Forest productivity has always been an essential consideration in stand management. Site index has been the most widely used measure of forest productivity, as well as site productivity, or the inherent capacity of a site to support tree growth (Jones 1969; Carmean 1975; Spurr and Barnes 1980; Hagglund 1981; Clutter *et al.* 1983; Monserud 1988; Thrower 1989)[1]. We adopted site index as a species-specific measure of forest productivity, recognizing that it only indicates height growth performance at a selected point in time.

The term **site quality** is often used ambiguously to denote both forest productivity and ecological site quality. However, two different tree species growing on the same site may have a different site index, or the same tree species may have the same site index on two ecologically different sites. Therefore, site index is the measure of a given species' productivity. It cannot be considered a true measure of the ecological quality of the site, nor can ecological site quality be considered a true measure of forest productivity. Thus, it is more appropriate to use the term **ecological site quality** than site quality when describing the ecological characteristics of a forest site.

If forest productivity is to be correlated with ecological site quality, what site data should be evaluated to clarify the relationships? The biogeoclimatic ecosystem classification defines the site as the physical environment (climate, topography, and soil) of a geographically circumscribed ecosystem, and organizes these ecosystems into environmentally characterized site units with the aid of vegetation (Pojar *et al.* 1987). This implies a recognition of different kinds of sites, each with varying ecological conditions or quality for plant growth.

While it is fairly easy to work with individual environmental factors, it is very difficult to determine their integrated effect on plants. Because of compensating effects, sites with different combinations of individual environmental factors can have similar ecological quality (Bakuzis 1969; Assmann 1970; Damman 1979). To circumvent this problem, ecologists and physiologists have identified four primary factors that directly influence plant establishment, survival, and growth: **climate** (light and temperature), **soil moisture**, **soil nutrients**, and **soil aeration** (Cajander 1926; Pogrebnyak 1930; Major 1951; Hills 1952; Krajina 1969; Tilman 1988; Grier *et al.* 1989; Kozlowski *et al.* 1991). The diagnosis of ecological site quality requires determination of the expression or value of these primary factors.

Relationships between site index and ecological site quality have been the focus of recent research efforts in British Columbia. Kabzems and Klinka (1987a, b), Courtin *et al.* (1988), Green *et al.* (1989), Carter and Klinka (1990, 1991), Klinka and Carter (1990), Kayahara (1992), Q. Wang (1992), and G. Wang (1993) used categorical measures of ecological site quality to explain the variation in site index of major tree species. This study expands these efforts to lodgepole pine and interior spruce. Our study and the previous studies are parts of a co-ordinated effort that aims to establish a link between biogeoclimatic ecosystem classification and growth and yield studies. These studies also address the call by Grier *et al.* (1989) for regional surveys of site productivity and for examining the relation between the various site factors and forest productivity. If the biogeoclimatic ecosystem classification is an appropriate ecological classification system, then it should yield useful measures of ecological site quality to explain the variation in productivity of different tree species on different forest sites.

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[1] Thrower, J.S. 1989. Site quality evaluation using site index. B.C. Min. For., Res. Branch, Victoria, B.C. II p. Unpublished report.

MATERIALS AND METHODS

One hundred and fifteen sample plots were located in naturally established, unmanaged, even-aged stands without a history of damage, and in lodgepole pine stands without an identifiable history of height growth repression (Table 1). Data from 18 lodgepole pine plots (Q. Wang 1992) and 15 interior spruce plots (G. Wang 1993) were also included. The stands studied averaged 75 years in age, were uniformly stocked (60–90% tree layer cover), and were located close to minor and major access roads situated north and south of Smithers, Telkwa, Houston, and Burns Lake. Each stand had a more or less uniform, single tree layer, that featured dominants of one or two study species (Appendix 1).

TABLE 1. General characteristics of lodgepole pine and interior spruce stands studied

Characteristic	Minimum	Mean	Maximum
Latitude	53° 55′ N	54° 20′ N	55° 05′ N
Longitude	126° 30′ W	127° 45′ W	128° 25′ W
Elevation (m)	505	760	940
Lodgepole pine (n = 93)			
Stand age (at breast height)	25	71	154
Site index (m/50 yr)	8.9	18.0	24.8
Interior spruce (n = 77)			
Stand age (at breast height)	34	78	140
Site index (m/50 yr)	4.3	17.2	25.4

The stands were located in two geographically adjacent subzones of the Sub-Boreal Spruce (SBS) zone, each of which represented a variation of montane boreal climate — dry and cool (SBSdk) and moist and cold (SBSmc) (Meidinger and Pojar 1991) (Table 2). A more complete description of the climate, vegetation, and soil of the subzones was given by Pojar *et al.* (1984). The portion of the SBSmc subzone situated in the Prince Rupert Forest Region represents the Babine (SBSmc2) variant, therefore the results reported here may not apply to the Moffat (SBSmc1) and Kluskus (SBSmc3) variants.

In each stand, a 20×20 m (0.04 ha) plot was located to represent an individual ecosystem with relatively uniform soil, understorey vegetation, and stand characteristics. The sample plots reflect the widest possible gradient of ecological site quality for each of the tree species studied (Verbyla and Fisher 1989).

Site, soil, and vegetation of each plot were described using the site diagnosis forms developed at the Forest Sciences Department, University of British Columbia. The climate (represented by biogeoclimatic subzone) was identified according to its location from the map of Pojar *et al.* (1988) . Soil moisture regimes (SMRs) and soil nutrient regimes (SNRs) were estimated in the field using a combination of topographic and soil morphological properties and the methods described by Klinka *et al.* (1984).

Each regional climate has a unique soil moisture gradient, but has the same set of relative SMRs ranging from 0 to 8. The driest soil in any climate is always designated very xeric (0) and the wettest is always designated hydric (8) (Klinka *et al.* 1984, 1989; Pojar *et al.* 1987). Consequently, the same relative SMRs do not signify the same amount of soil water available for evapotranspiration by vascular plants, particularly in the upper half of the relative scale (0–4). For example, a very xeric soil (0) in a very dry and warm climate will likely have a high growing season water deficit, while in a very wet and cool climate the same soil will likely have low or no water deficit.

TABLE 2. Some climatic characteristics of the SBSdk and SBSmc subzones using the data from the selected stations in the study area

Subzone	SBSdk	SBSmc
Climatic station[a]	Telkwa	Fort Babine
Elevation (m)	683	716
Mean annual precipitation (mm)	468.3	600.5
Mean annual snowfall (as % of mean annual precipitation)	43.5	43.4
Mean precipitation, May–Sept. (mm)	212.7	247.6
Mean precipitation: driest summer month (mm)	27.9	36.5
Mean precipitation: wettest winter month (mm)	49.8	66.3
Mean annual temperature (°C)	2.9	1.2
Mean temperature of the warmest month (°C)	14.3	13.0
Mean temperature of the coldest month (°C)	-11.3	-14.3
Potential evapotranspiration (E_{max} mm/May–Sept.)	247.1	231.0
Actual evapotranspiration (E_t mm/May–Sept.) on zonal sites	210.6	222.6
E_t/E_{max} on zonal sites	0.85	0.96
Water deficit (mm/May–Sept.) on zonal sites	36.5	8.4
Index of continentality	33.0	36.9

[a] Environment Canada (1982).

The study of vegetation environment relationships and the interpretation of ecosystems across a wide range of climates requires knowledge of actual soil moisture and nutrient conditions. This involves the integration of many regional soil moisture and nutrient gradients, and the development of actual soil moisture and nutrient regimes.

The actual soil moisture regime describes the average amount of soil water available for plants (Major 1963, 1977; Soil Survey Staff 1975). The site's relative SMR was estimated and converted it to an actual SMR by using established correlations between relative and actual SMRs for a given biogeoclimatic subzone (Table 3). This study adopted the criteria proposed by Klinka *et al.* (1989), and used the Energy/Soil Limited model of Spittlehouse and Black (1981) to calculate growing-season potential evapotranspiration (E_{max}), actual evapotranspiration (E_t), and water deficit for each of the 18 SBSmc lodgepole pine plots established by Q. Wang (1992) and the 15 SBSdk interior spruce plots established by G. Wang (1993). Each of these plots was then assigned an actual SMR, either according to the E_t/E_{max} ratio, or the depth of growing season water table or gleyed soil horizon (Table 3). The actual SMR for the remaining 115 sample plots was obtained by converting field-estimated relative SMRs using the correlations established for the 33 intensively studied sample plots.

For actual soil nutrient regimes, this study adopted the criteria identified for the SBS zone by Q. Wang (1992) who characterized the field-estimated, traditionally used SNRs by selected soil chemical properties and the frequency of nitrophytic plants (Table 4). Using the developed correlations between qualitative and quantitative criteria, each study plot was assigned to an SNR based on soil morphological properties and understorey vegetation of the plot.

When the regional climate (biogeoclimatic subzone), and actual SMR and SNR for each sample plot (Appendices 2 and 3) were determined, study stands were stratified according to climate, actual SMR, actual SNR, and actual SMR and SNR combinations or **edatopes** (Appendices 4 and 5). The stands were then assigned into site series recognized by the B.C. Forest Service's Ecological Program Staff in the SBSdk and SBSmc subzones (A. Banner, pers. comm.).

TABLE 3. Differentiating characteristics for actual soil moisture regimes (SMRs) and their relationship to relative SMRs in the SBSdk and SBSmc subzones (after Q. Wang 1992)

Characteristic	Actual SMR	Relative SMR	
		SBSdk	SBSmc
1a. Prolonged water deficit occurs			
2a. E_t/E_{max} >0.40 but ≤0.60[a]	very dry (VD)	0	0
2b. E_t/E_{max} >0.60 but <0.90	moderately dry (MD)	1–2	1–2
2c. E_t/E_{max} ≥0.90	slightly dry (SD)	3–4	3
1b. Prolonged water deficit does not occur			
3a. Utilization of soil-stored water occurs and growing-season water table or gleyed soil horizons absent	fresh (F)	5	4
3b. No utilization occurs or growing-season water table or gleyed soil horizons present			
4a. Growing-season water table or gleyed soil horizon ≥60 cm deep	moist (M)	6	5
4b. Growing-season water table or gleyed soil horizon >30 cm but <60 cm	very moist (VM)	6	6
4c. Growing-season soil water table or gleyed soil horizon ≤30 cm deep but >0 cm	wet (W)	7	7
4d. Growing-season water table at or above the ground surface	very wet (VW)	8	8

[a] E_t/E_{max} = actual evapotranspiration/potential evapotranspiration ratio.

TABLE 4. Means and standard deviations (in parentheses) of the forest floor and mineral soil properties and frequency of nitrophytic plants (F_{NITR3}) used to characterize soil nutrient regimes in the Sub-Boreal Pine— Spruce (SBPS) and SBS zones (from Q. Wang 1992)

Property	Soil nutrient regime				
	Very poor (VP) (n=6)	Poor (P) (n=15)	Medium (M) (n=21)	Rich (R) (n=20)	Very rich (VR) (n=10)
Forest floor					
pH	4.3	4.3	4.4	5.3	5.9
	(0.2)	(0.4)	(0.7)	(0.8)	(0.5)
C/N	63	50	39	39	29
	(9.6)	(12)	(6.5)	(6.6)	(3.8)
Total P (kg/ha)	15	33	67	94	302
	(8)	(13)	(51)	(45)	(203)
Total S (kg/ha)	21	39	58	118	474
	(11)	(23)	(57)	(83)	(479)
Mineral soil					
pH	5.9	5.5	5.1	6.1	6.1
	(0.3)	(0.4)	(0.7)	(0.9)	(0.5)
C/N	95	65	35	39	33
	(32)	(17)	(15)	(12)	(15)
Forest floor and mineral soil					
Mineralizable N (kg/ha)	2.7	9.7	30	38	130
	(0.9)	(3.1)	(13)	(13)	(79)
Exchangeable Ca, Mg, and K (kg/ha)	1203	1040	1376	3960	8278
	(291)	(789)	(1641)	(1875)	(3627)
Frequency of nitrophytic plants					
F_{NITR3}	1.5	3.7	9.3	25.2	38.2
	(0.8)	(2.9)	(14.7)	(19.4)	(21.1)

In each sample plot, the five largest diameter (dominant) trees of the one or two species studied with no obvious evidence of growth abnormalities and damage were measured for breast-height age (bha) using an increment borer, and top height, using a Suunto clinometer. Site index was taken from the height growth tables of Goudie[2] for lodgepole pine and of Goudie and Mitchell[3] for interior spruce.

Biogeoclimatic subzone, actual SMR, and SNR, and site series (Appendices 2 and 3) were used as independent categorical variables in stratification, analysis of variance, and regression analysis for each study species. Site index was tested for normality using graphical analysis (probability plots) (Chambers *et al.* 1983; Wilkinson 1990). One-way analysis of variance (ANOVA) and Tukey's test (Zar 1984) were conducted to detect differences in site index among groups of plots stratified according to categorical variables. Simple and multiple regressions were used to examine relationships between site index and ecological site quality (Chatterjee and Price 1977). The relationships examined are outlined in Table 5.

Means and standard deviations of site index were shown in categorical plots (Wilkinson 1990). A distance-weighted least squares (DWLS) smoothing method (McLain 1974; Wilkinson 1990) was used to superimpose the isolines of site index onto edatopic grids. All data were summarized and analyzed using the SYSTAT and SYGRAPH statistical packages (Wilkinson 1990), with the aid of the QUATTRO PRO spreadsheet package (Borland International Inc. 1989).

TABLE 5. Synopsis of the regression models used to test relationships between site index (SI, metres at 50 yr [bha]) and selected categorical variables

[1]	**SI = *f*(BGCSs)** where BGCSs (biogeoclimatic subzones) are dummy variables representing SBSdk and SBSmc subzones.
[2]	**SI = *f*(SMRs)** where SMRs are dummy variables representing actual soil moisture regimes: VD = very dry, MD = moderately dry, SD = slightly dry, F = fresh, M = moist, VM = very moist, W = wet, and VW = very wet.
[3]	**SI = *f*(SNRs)** where SNRs are dummy variables representing actual soil nutrient regimes: VP = very poor, P = poor, M = medium, R = rich, and VR = very rich.
[4]	**SI = *f*(SMRs, SNRs)** where SMRs and SNRs are dummy variables defined above.
[5]	**SI = *f*(BGCSs, SMRs, SNRs)** where BGCS, SMRs, and SNRs are dummy variables defined above.
[6]	**SI = *f*(SSs)** where SSs are dummy variables representing site series defined in Table 8 for each subzone.

[2] Goudie, J.W. 1984. Managed stand yield tables for interior lodgepole pine: initial and post-spacing density. B.C. Min. For., Victoria, B.C. 14 p. Unpublished report.
[3] Goudie, J.W. and K. Mitchell. 1986. The first approximation of managed stand yield tables for interior white spruce. B.C. Min. For., Victoria, B.C. 35 p. Unpublished report.

RESULTS

Relationships Between Site Index and Climate

Stratification of lodgepole pine and interior spruce stands by biogeoclimatic subzone did not indicate any significant change of site index with climate (Figures 1 and 2). Comparing only lodgepole pine stands zonal edatopes (i.e., slightly dry (4) and nutrient-medium in the SBSdk subzone; fresh (4) and nutrient-medium in the SBSmc subzone), the mean site index increased from 18.9 m in the SBSdk subzone to 21.1 m in the SBSmc subzone. A similar comparison of site index for interior spruce showed a slight decrease from 17.8 m in the SBSdk subzone to 17.4 m in the SBSmc subzone.

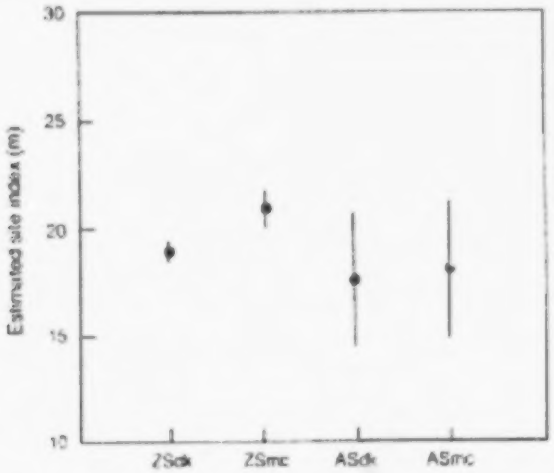

FIGURE 1. Categorical plot of lodgepole pine site index for zonal study sites (ZS) and all study sites (AS) relation to biogeoclimatic subzones. Vertical bars represent ± one standard deviation.

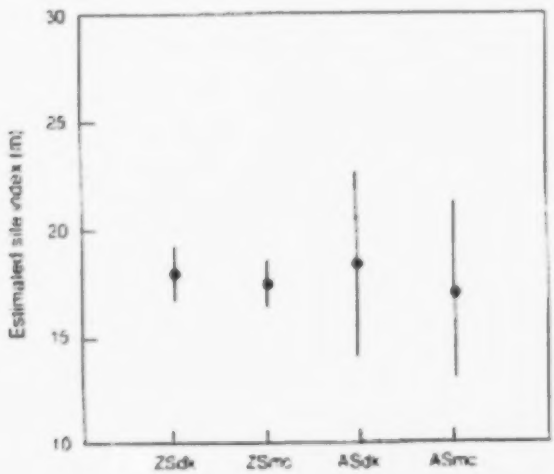

FIGURE 2. Categorical plot of interior spruce site index for zonal study sites (ZS) and all study sites (AS) relation to biogeoclimatic subzones. Vertical bars represent ± one standard deviation.

Relationships Between Site Index and Soil Moisture

There were similar and strong relationships between site index of lodgepole pine and interior spruce and actual soil moisture regimes (Table 6). Mean site index of both species increased from very dry to fresh sites, reached a plateau (approximately 20 m) on fresh and moist sites — the region of most productive growth for both species — and decreased from moist to very wet sites. Although the spruce site index was considerably lower than that of the lodgepole pine on very dry and wet sites, interspecific differences were not significant for any SMRs ($\alpha = 0.05$). The one-way analysis of variance and Tukey's test indicated the presence of a weak productivity gradient for both species coinciding with the assumed soil moisture gradient (Table 6).

TABLE 6. Number of stands and means and standard deviations (in parentheses) of site index (SI, metres at 50 yr [bha]) of the stands studied, stratified by species and actual soil moisture regimes (SMRs). Abbreviations for actual SMRs are explained in Table 3. Values in the same row with different uppercase superscripts and in the same column with different lowercase superscripts are significantly different ($\alpha = 0.05$, Tukey's test).

Species	Soil moisture regime							
	VD	MD	SD	F	M	VM	W	VW
Lodgepole pine	$14.2^{B,a}$	$15.2^{B,a}$	$17.9^{A,a}$	$20.8^{A,a}$	$20.1^{A,a}$	$17.0^{B,a}$	$15.2^{b,a}$	8.9
	(6.1)	(2.2)	(1.2)	(2.5)	(2.0)	(3.6)	(2.1)	(0.0)
	n=2	n=18	n=25	n=22	n=10	n=13	n=2	n=1
Interior spruce	$8.0^{D,a}$	$14.4^{C,a}$	$17.9^{B,a}$	$20.4^{A,a}$	$19.7^{A,B,a}$	$18.8^{A,B,a}$	$10.9^{C,D,a}$	4.3
	(1.6)	(1.7)	(2.0)	(2.6)	(1.2)	(3.4)	(6.9)	(0.0)
	n=3	n=12	n=16	n=25	n=8	n=10	n=2	n=1

Relationships Between Site Index and Soil Nutrients

Stratification of stands by soil nutrient regimes showed a different relationship for each species (Table 7). Mean lodgepole pine site index increased from very poor to rich sites. The rate of increase decreased with greater nutrient availability, and reached a plateau (approximately 20 m) on rich and very rich sites. There was no significant difference in site index between medium, rich and very rich sites — the region of most productive growth. In comparison to lodgepole pine, the interior spruce site index increased consistently from very poor to very rich sites, reaching a maximum of approximately 23 m. The one way analysis of variance and Tukey's test indicated that the relationship between productivity and assumed nutrient gradients was weak for lodgepole pine but strong for spruce (Table 7). Comparisons to lodgepole pine indicated that the interior spruce site index was significantly lower on very poor, poor, and medium sites, but there were no significant differences on rich and very rich sites.

TABLE 7. Number of stands, and means and standard deviations (in parentheses) of site index (SI, metres at 50 yr [bha]) of the stands studied, stratified by species and soil nutrient regimes (SNRs). Abbreviations for SNRs are explained in Table 4. Values in the same row with different uppercase superscripts and in the same column with different lowercase superscripts are significantly different ($\alpha = 0.05$, Tukey's test).

Species	Soil nutrient regime				
	VP	P	M	R	VR
Lodgepole pine	$12.3^{C,a}$	$16.1^{B,a}$	$19.2^{A,a}$	$20.6^{A,a}$	$20.2^{A,a}$
	(1.3)	(2.3)	(1.5)	(2.2)	(4.1)
	n=8	n=29	n=30	n=23	n=3
Interior spruce	$6.2^{E,b}$	$13.5^{D,b}$	$16.9^{C,b}$	$19.3^{B,a}$	$22.9^{A,a}$
	(0.2)	(3.0)	(1.8)	(3.7)	(2.5)
	n=2	n=12	n=23	n=32	n=8

Relationships Between Site Index and Site Series

Stratification of stands by site series showed weak relationships to site index (Table 8). The previously described relationships between mean site index and climate, soil moisture, and soil nutrients were detectable for both lodgepole pine and interior spruce. In the SBSdk subzone, the Sxw–Twinberry–Coltsfoot site series supported the most productive growth of lodgepole pine, while the most productive growth of interior spruce occurred in the Sxw–Twinberry–Coltsfoot and Sxw–Horsetail site series. In the SBSmc subzone, the most productive growth of both species occurred in five site series: Sxw–Huckleberry, Sxw–Oak fern, Sxw–Twinberry–Coltsfoot, Sxw–Devil's club, and Sxw–Horsetail. Two groups of site series could be recognized: (1) a low site index group (SI <18 m) related to water-deficient or water-surplus and nutrient-deficient sites, and (2) a high site index group (SI ≥18 m) related to other sites of the edaphic spectrum.

TABLE 8. Range of relative and actual soil moisture regimes (SMRs) and soil nutrient regimes (SNRs), number of study stands (N), and means (M) and standard deviation (S) of site index (SI, at metres 50 yr [bha]) for studied SBSdk and SBSmc site series. Abbreviations for SMRs and SNRs are explained in Tables 3 and 4, respectively. Values in the same column and within the same subzone with different superscripts are significantly different ($\alpha = 0.05$, Tukey's test).

Site series	SMR		SNR	Lodgepole pine			Interior spruce		
	Relative	Actual		N	M	S	N	M	S
SBSdk subzone									
02 Pl–Juniper–Ricegrass	0	VD	VP–M				2	8.0^{c}	2.3
03 Pl–Feathermoss–Cladina	1–2	MD	VP–M	11	15.4^{b}	2.1	8	15.2^{b,c}	1.3
05 Sxw–Spiraea–Feathermoss	3–5	SD–F	VP–P						
01 Sxw–Spiraea–Purple peavine	3–5	SD–F	P–M	12	17.4^{b}	1.9	8	17.3^{b}	1.4
06 Sxw–Twinberry–Coltsfoot	4–6	SD–M	M–VR	11	21.8^{a}	1.8	21	20.8^{a}	2.4
07 Sxw–Horsetail	6	VM	M–VR	1	18.1	na	4	21.5^{a}	2.0
09 Sb–Creeping snowberry–Sphagnum	6–7(–8)	M–W(–VW)	VP–P	5	15.7^{b}	2.8	2	10.5^{c}	6.4
SBSmc subzone									
02 Pl–Huckleberry–Cladina	0–2	VD–MD	VP–M	9	15.5^{b}	3.2	5	11.8^{b}	2.3
01 Sxw–Huckleberry	3–4	SD–F	P–R	18	18.9^{a}	1.8	7	17.4^{a}	2.1
05 Sxw–Twinberry–Coltsfoot	5	M	M	1	19.5	na	2	18.6^{a}	0.5
06 Sxw–Oak fern	4	F	R–VR	6	20.2^{a}	2.1	5	19.9^{a}	2.3
07 Sxw–Scrub birch–Feathermoss	5–6	M–VM	VP–P	3	13.1^{b}	2.5	1	12.3	na
09 Sxw–Devil's club	5	M	R–VR	7	20.0^{a}	1.5	6	20.1^{a}	1.2
10 Sxw–Horsetail	6	VM	M–VR	6	19.8^{a}	1.3	4	18.6^{a}	1.5
12 SbSxw–Scrub birch–Sedge	7(–8)	W(–VW)	P–VR	3	13.1^{b}	3.9	2	10.0^{b}	8.1

Regression Analysis

Six regression models (Table 5) were developed to test relationships between site index and categorical measures of ecological site quality for lodgepole pine and interior spruce (Tables 9 and 10, respectively). All models were significant ($\alpha = 0.05$) except for the climatic models (equations [1a] and [1b]).

The climatic models showed no relationships with site index and inclusion of biogeoclimatic subzone as a categorical variable into the edatope models (equation [5], Tables 9 and 10) did not significantly improve their performance. These results corroborate the earlier comparison, and suggest that the relationship between forest productivity and assumed climatic gradients is weak for both species.

The SMR and SNR variables (equations [2] and [3], Tables 9 and 10) each had moderate relationships with site index, but the edatope models (equation [4], Tables 9 and 10) accounted for the largest proportion of the variation in site index (R^2 >80%) and gave the lowest standard error (ranging from 1.4 to 1.6 m) for each species (Figures 3 and 4). Actual SMR and SNR were found to exhibit a high collinearity. Consequently, the effect of changes in either of these categorical variables cannot be examined independently. Although site series models (equation [6], Tables 9 and 10) explained a significant proportion of the variation in site index for both species, these models were less precise compared to edatope models.

TABLE 9. Models for the regression of lodgepole pine site index (SI, metres at 50 yr [bha]) on selected categorical variables (n = 93). Abbreviations used for dummy variables are explained in Table 5.

[1a] SI = 18.21 - 0.44(SBSdk) - 0.00(SBSmc)[a]
Adjusted R^2 = 0.01 Standard Error of Estimate (SEE) = 3.2 m

[2a] SI = 8.90 + 5.25(VD) + 6.68(MD) + 9.04(SD) + 11.92(F) + 11.18(M) + 8.08(VM) + 6.30(W) + 0.00(VW)
Adjusted R^2 = 0.45 SEE = 2.4 m

[3a] SI = 20.23 - 7.98(VP) - 4.11(P) - 1.09(M) + 0.51(R) + 0.00(VR)
Adjusted R^2 = 0.60 SEE = 2.0 m

[4a] SI = 14.17 - 9.27(VP) - 5.27(P) - 3.11(M) - 1.72(R) - 0.00(VR) + 4.17(VD) + 6.85(MD) + 8.13(SD) + 9.33(F) + 8.48(M) + 6.97(VM) + 1.89(W) + 0.00(VW)
Adjusted R^2 = 0.82 2SEE = 1.4 m

[5a] SI = 14.21 + 0.52(SBSdk) + 0.00(SBSmc) - 9.41(VP) - 5.31(P) - 3.06(M) - 1.61(R) - 0.00(VR) + 4.12(VD) + 6.52(MD) + 7.84(SD) + 8.98(F) + 8.26(M) + 6.76(VM) + 1.79(W) + 0.00(VW)
Adjusted R^2 = 0.82 SEE = 1.4 m

[6a] SBSdk subzone (n = 40)

SI = 15.38 + 0.00(SS03) + 2.03(SS05) + 6.43(SS06) + 2.72(SS07) + 0.34(SS09)
Adjusted R^2 = 0.59 SEE = 2.1 m

SBSmc subzone (n = 53)

SI = 18.85 + 0.00(SS01) - 3.34(SS02) + 0.65(SS05) + 1.35(SS06) - 5.79(SS07) + 2.16(SS09) + 0.98(SS10) - 5.75 (SS12)
Adjusted R^2 = 0.53 SEE = 2.2 m

[a] Model is not significant at α = 0.05.

TABLE 10. Models for the regression of interior spruce index (SI, metres at 50 yr [bha]) on selected categorical variables (n = 77). Abbreviations used for dummy variables are explained in Table 5.

[1b] SI = 17.01 + 1.17(SBSdk) + 0.00(SBSmc)[a]
Adjusted R^2 = 0.01 Standard Error of Estimate (SEE) = 4.2 m

[2b] SI = 4.30 + 3.67(VD) + 10.08(MD) + 13.59(SD) + 16.05(F) + 15.38(M) + 14.45(VM) + 6.55(W) + 0.00(VW)
Adjusted R^2 = 0.65 SEE = 2.5 m

[3b] SI = 22.89 - 16.74(VP) - 9.43(P) - 6.03(M) - 3.58(R) - 0.00(VR)
Adjusted R^2 = 0.58 SEE = 2.7 m

[4b] SI = 7.13 - 10.09(VP) - 7.17(P) - 5.05(M) - 2.83(R) - 0.00(VR) + 9.25(VD) + 13.01(MD) + 15.37(SD) + 16.10(F) + 15.58(M) + 14.97(VM) + 10.58(W) + 0.00(VW)
Adjusted R^2 = 0.85 SEE = 1.6 m

[5b] SI = 6.90 + 8.36(VD) + 11.81(MD) + 13.90(SD) + 15.02(F) + 15.62(M) + 14.10(VM) + 10.08(W) + 0.00(VW) - 11.87(VP) - 6.80(P) - 5.10(M) - 2.56(R) - 0.00(VR) + 1.80(SBSdk) + 0.00(SBSmc)
Adjusted R^2 = 0.89 SEE = 1.4 m

[6b] SBSdk subzone (n = 45)

SI = 7.95 + 0.00(SS02) + 7.24(SS03) + 9.30(SS05) + 12.81(SS06) + 13.53(SS07) + 2.55(SS09)
Adjusted R^2 = 0.72 SEE = 2.3 m

SBSmc subzone (n = 32)

SI = 17.4 + 0.00(SS01) + 1.15(SS05) + 2.48(SS06) - 5.10(SS07) + 2.65(SS09) + 1.18(SS10) - 7.40(SS12)
Adjusted R^2 = 0.63 SEE = 2.5 m

[a] Model is not significant at α = 0.05.

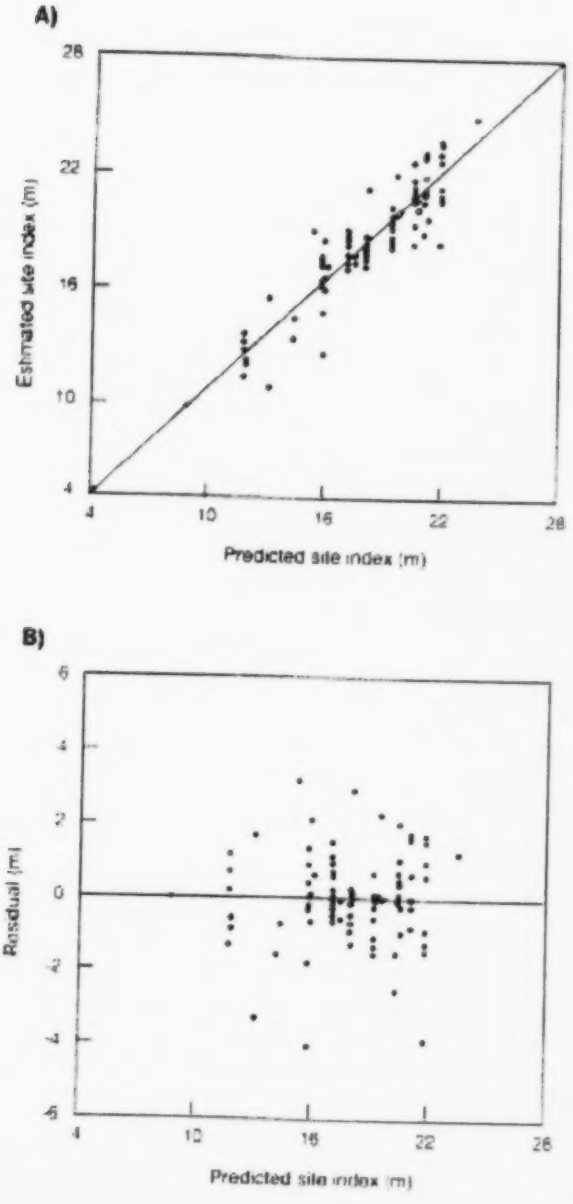

FIGURE 3. Residual analysis for equation [4a] (Table 9): (A) estimated against predicted lodgepole pine site index (metres at 50 yr [bha]), and (B) residuals against predicted lodgepole pine site index.

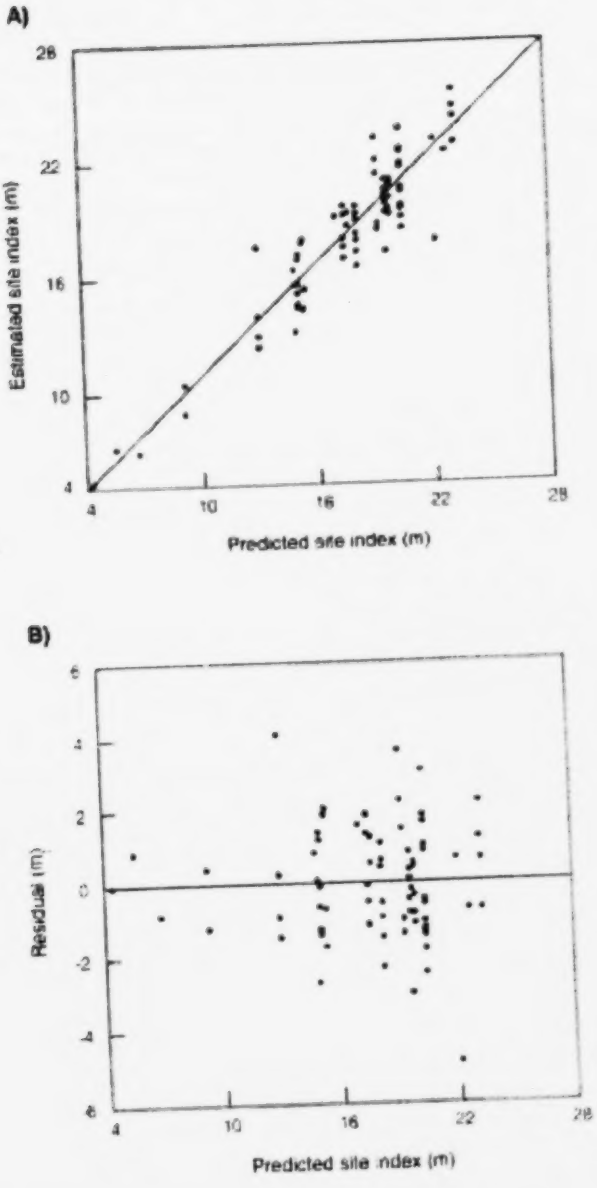

FIGURE 4. Residual analysis for equation [4b] (Table 10): (A) estimated against predicted interior spruce site index (metres at 50 yr [bha]), and (B) residuals against predicted interior spruce site index.

DISCUSSION

Equal representation of stands in the biogeoclimatic subzones, and soil moisture and nutrient regimes would be the most desirable situation for the study of relationships between site index and ecological site quality. However, certain climatic, soil moisture, and soil nutrient combinations may not occur or occur very rarely in the landscape. The usual sequence of sites in a topographically diversified landscape proceeds in a diagonal direction — that is, from water-deficient and nutrient-poor sites to water-surplus and nutrient-rich sites. Such a diagonal sequence was present and sampled in the study area (Appendices 4 and 5).

Both the lodgepole pine and interior spruce stands were poorly represented on very dry, wet, and very wet sites. A poor representation also was evident for lodgepole pine stands on very rich sites, and for spruce stands on very poor sites. Consequently, our analysis of site index-ecological site quality relationships suffered from missing values and poor representation of some edatopes when the study stands were stratified according to SMRs and SNRs. Therefore, the validity of site index predictions obtained by extrapolation (for the edatopes with missing values) or based on means estimated from very few stands (for poorly represented edatopes) may be questioned.

Despite a limited or poor representation of climates and certain combinations of SMRs and SNRs, the large amount of variation explained by the edatope models revealed strong relationships between lodgepole pine and interior spruce site indices and categorical measures of ecological site quality. The results obtained conform well with those reported for coastal Douglas-fir in the Coastal Western Hemlock zone by Carter and Klinka (1990) and Klinka and Carter (1990), for lodgepole pine in the SBS zone by Q. Wang (1992), and for interior spruce in the SBS zone by G. Wang (1993).

The inferior fit and the lack of precision of the site series models compared to the edatope models was attributed to broad edatopic ranges of SBSdk and SBSmc site series and poor representation of stands for some site series. Site series usually represent a range of edatopes and therefore provide a more generalized framework for describing site index/ecological site quality relationships than edatopes. However, in this study site identification was often problematic as site series were characteristized by understorey vegetation, and a half-unit SMR and SNR was used to define their edatopic limits in some cases. For example, the moist (5 or subhygric) and nutrient-rich edatope in the SBSmc subzone contains three site series: Sxw–Twinberry–Coltsfoot, Sxw–Oak fern, and Sxw–Devil's club. The stands studied were in the early- to mid-seral stages, with understorey vegetation that was poorly developed or even lacking and that had commonly been disturbed. We were able to use only a one-unit SMR and SNR and, if given, other environmental factors or properties for the consistent and definitive identification of site series (see Pojar *et al.* 1987). We therefore had to make some arbitrary decisions in site identification (Table 8) which might have affected performance of the site series models.

Both lodgepole pine and interior spruce have a wide ecological amplitude in relation to climate, soil moisture, and soil nutrient gradients (Krajina 1969; Lotan and Critchfield 1990; Nienstaedt and Zasada 1990). Growth performance of these species increases with increasing potential evapotranspiration from cool to warm climates. Within the SBS zone, site index will also increase from relatively cooler to warmer climates, presumably reflected by biogeoclimatic subzones. Insignificant differences in site index for both lodgepole pine and interior spruce between zonal sites indicate that the SBSdk and SBSmc subzones are climatically similar. A similar situation was suggested by Laing and McCulloch (1988) for the SBSmc and ICHmc subzones.

It may be that the differences in precipitation and temperature between the subzones studied do not exert a significant influence on forest growth by actual evapotranspiration. This is probably because of compensating effects between precipitation and temperature. The higher temperatures in the SBSdk subzone create a greater potential (based on potential evapotranspiration) for vascular plant activity than in the SBSmc subzone (Table 2). However, this potential is not likely realized because of a lower precipitation in the SBSdk subzone. Higher precipitation (and lower water deficit) in the SBSmc subzone is responsible for a slightly higher actual evapotranspiration relative to the SBSdk subzone. Because of this weak climatic

(actual evapotranspiration) gradient between the SBSdk and SBSmc subzones, site index/ecological site quality relationships in the stands can be examined and justified without considering a climatic factor.

However, comparing McLennan's site index statistics (1989) for lodgepole pine and interior spruce in the SBSdk and SBSmc subzones to our data reveals some discrepancies (Table 11). Although the mean lodgepole pine site index in the SBSdk subzone is very similar in both studies, McLennan reports a 2.3 m decrease. The present study determined a 2.2 m increase in the SBSmc subzone. McLennan's data show a similar trend for interior spruce, but, in contrast to the present study, these values are considerably and consistently lower (Table 11).

TABLE 11. Number of stands, and means and standard deviations (in parentheses) of site index (SI, metres at 50 yr [bha]) on zonal sites in the SBSdk and SBSmc subzones for this and McLennan's (1989) studies

Species	SBSdk subzone		SBSmc subzone	
	This study	McLennan	This study	McLennan
Lodgepole pine	18.9 (0.48) n=4	18.1 (2.80) n=31	21.1 (0.85) n=5	15.8 (2.65) n=10
Interior spruce	17.8 (1.25) n=5	14.7 (3.44) n=23	17.4 (1.12) n=4	13.2 (5.78) n=4

These discrepancies may be attributed to three factors: differences in the edatopic range of zonal sites, seral stage, and selection of site trees. First, zonal sites of our study represented mesic and nutrient-medium conditions (Pojar *et al.* 1987), whereas those analyzed by McLennan included slightly dry to fresh and nutrient-poor to -rich sites. With an equal representation of stands by edatopes, the broader edatopic range would tend to increase standard deviation but not mean site index values. McLennan reports considerably higher standard deviations than this study. However, these low mean site index values for lodgepole pine in the SBSmc subzone and for interior spruce in both SBSdk and SBSmc subzones may suggest a poor representation of fresh and nutrient-rich sites in his zonal groupings. Second, the stands studied by McLennan were late-seral stands (ranging from 80 to 220 years) that were sampled for ecological classification in the SBS zone. Most of the stands in this study were relatively young (ranging from 25 to 155 years). Finally, only dominant trees were selected to estimate site index in this study whereas McLennan used both dominant and codominant trees. All of these factors might have contributed to lower site index values reported by McLennan. This is especially true for interior spruce, as trees selected for estimates may have had a history of suppression.

Interior spruce site index was significantly lower than that of lodgepole pine on all but rich and very rich sites, suggesting that lodgepole pine is relatively less demanding of nutrients (within given soil moisture conditions) than interior spruce. Site index for both species was best on fresh to moist and nutrient very rich sites: 25 m and 24 m, for pine and spruce, respectively (Appendices 4 and 5). Our characterization of the edatopes supporting for the most productive growth of each species is in agreement with Krajina's (1969), with the most productive growth of lodgepole pine occurring on fresh to moist and rich sites. Very rich sites do not support the growth of the species and it is suggested that this is because of the difference in describing the soil nutrient gradient and regimes. Krajina considered very rich sites to have not only a very high available-nitrogen level but also to be calcium-rich, with pH >7 in the surface soil horizons. Indeed, lodgepole pine is rare on circumneutral soils and absent on alkaline soil (Krajina 1969; Cochran 1985).

Although the effect of changes in either SMR or SNR cannot be examined independently, and despite an unbalanced edatopic representation in the stands studied, the variation in site index along a soil moisture gradient was apparently higher than along a soil nutrient gradient for both species. Figures 5 and show that site index isolines for lodgepole pine and interior spruce are similar. Interior spruce shows more sensitivity to extremes in water deficit or water surplus and supply of available soil nitrogen than does

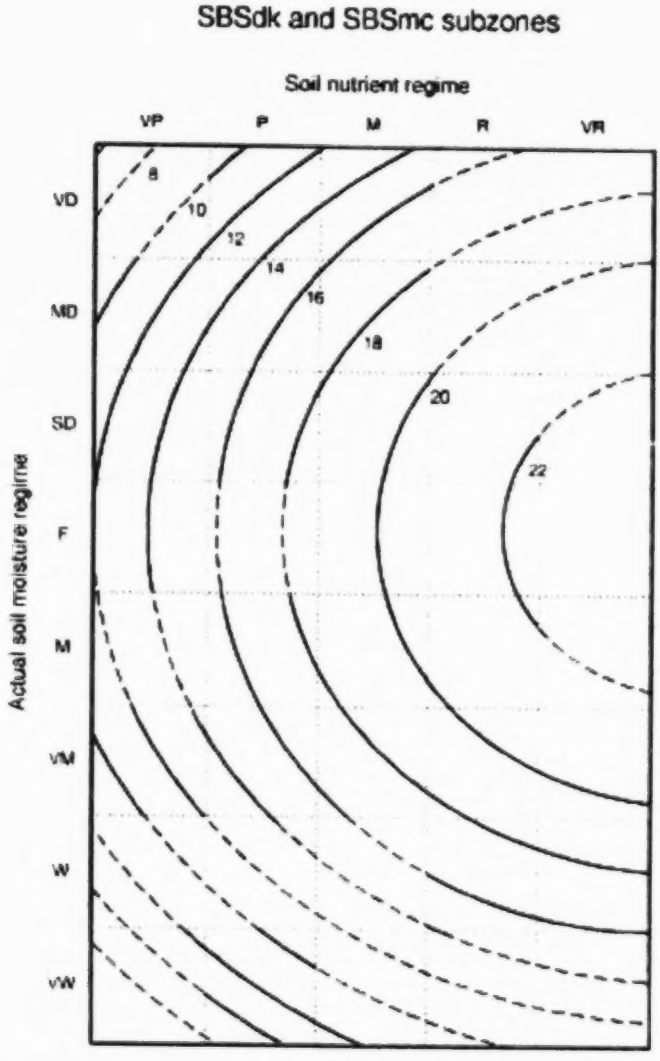

FIGURE 5. An edatopic grid showing lodgepole pine site index (metres at 50 yr [bha]) isolines for both SBSdk and SBSmc subzones calculated from equation [4a] (edatope model) and fitted using distance-weighted least squares smoothing algorithm. Dashed isolines are beyond the range of SMR–SNR combinations of the stands studied. Abbreviations for SMRs and SNRs are explained in Tables 3 and 4, respectively.

lodgepole pine. Interior spruce site index appears to equal or surpass (by approximately 2 m) lodgepole pine site index only in the slightly dry to very moist, and rich to very rich edatopic region. On all other sites, lodgepole pine site index appears higher than that for interior spruce, with the difference in favour lodgepole pine increasing (up to a maximum of 2 m) with decreasing supply of available nutrients and increasing water deficit or water surplus.

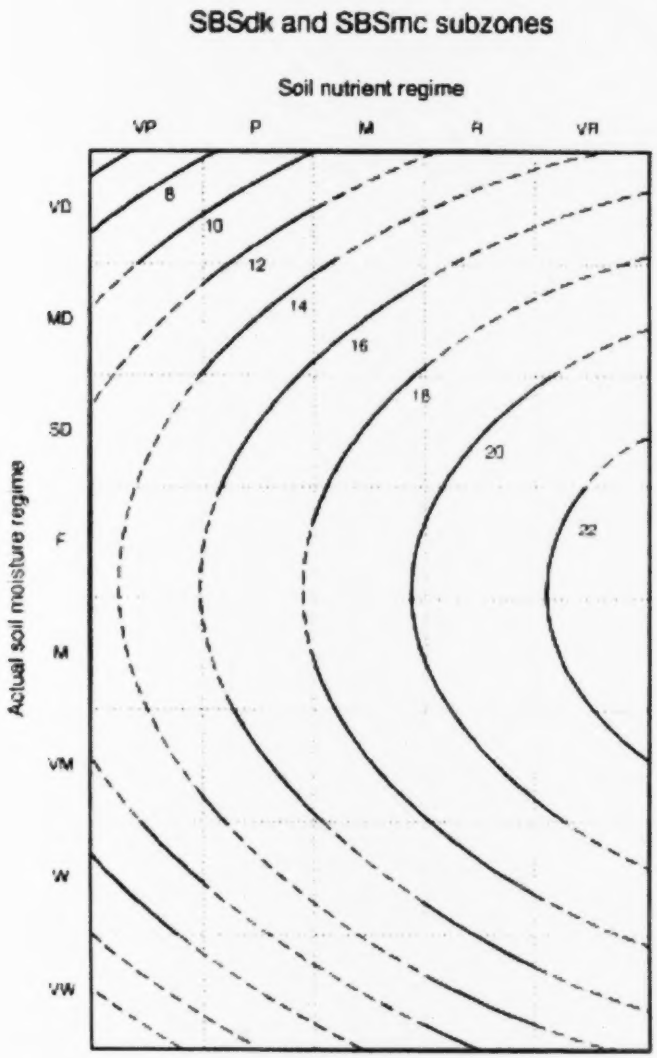

FIGURE 6. An edatopic grid showing interior spruce site index (metres at 50 yr [bha]) for both SBSdk and SBSmc subzones isolines calculated from equation [4b] (edatope model) and fitted using distance-weighted least squares smoothing algorithm. Dashed isolines are beyond the range of SMR–SNR combinations of the stands studied. Abbreviations for SMRs and SNRs are explained in Tables 3 and 4, respectively.

Interior spruce should always be considered a major crop species by site index and for the purpose of timber production in the slightly dry to very moist, and rich to very rich (most productive) edatopic region in the SBSdk and SBSmc subzones. Lodgepole pine should be considered a second major or minor species. On the remainder of the sites in both subzones, lodgepole pine should be considered a major crop species and spruce a minor crop species with its presence decreasing with decreasing supply of available nutrients and increasing water deficit or water surplus. Tree species selection decisions should also take into account (a) possible differences in volume or value of timber crops produced over the rotation, (b) crop reliability, (c) silvicultural feasibility, and (d) ecosystem biodiversity of different tree species combination options (Klinka and Feller 1984).

With the widespread use of biogeoclimatic classification, and the relationships between site index and ecological site quality analyzed, it is now possible to develop operational tools to estimate the site index of potential crop species on any forest site. This study has shown that site index isolines constructed from edatope models and superimposed onto edatopic grids can offer field forestry personnel a useful means of developing these tools (Krajina 1972), (Figures 5 and 6).

CONCLUSIONS

Strong and meaningful relationships were obtained when categorical measures of ecological site quality were used as independent variables to describe lodgepole pine and interior spruce site index in the SBSdk and SBSmc subzones. The most useful variables were soil moisture regime and soil nutrient regime. Biogeoclimatic subzone did not improve performance of the edatope models, probably because of climatic similarities between the subzones. The variation in site index of both species compared favourably with trends proposed by Krajina (1969). To estimate lodgepole pine and interior spruce site index, where direct estimates of site index are inappropriate, the use of isolines constructed from the edatope model is recommended provided the model is tested against an independent data set.

APPENDIX 1. List of stands studied (Pl = lodgepole pine, Sxw = interior spruce)

BUR3	Pl	OVEN12	Pl	SM44	Pl	WG69	Sxw
BUR5	Pl	SKI2	Sxw	SM46	Pl	WG70	Sxw
BUR6	Pl	SKI3	Pl, Sxw	SM47	Pl	WG71	Sxw
BUR7	Pl, Sxw	SKI4	Pl	SM48	Sxw	WG72	Sxw
EQU1	Pl, Sxw	SKI5	Pl	TEL1	Sxw		
EQU2	Sxw	SKI6	Pl	TEL2	Pl		
EQU4	Sxw	SKI7	Pl	TEL3	Pl, Sxw		
EQU6	Pl	SKI8	Pl	TEL4	Sxw		
EQU7	Pl	SKI9	Pl	TEL7	Pl		
EQU9	Pl	SKI10	Pl	TEL8	Sxw		
MOR1	Pl, Sxw	SKI11	Pl	TEL9	Sxw		
MOR2	Pl, Sxw	SKI12	Pl	TEL10	Sxw		
MOR3	Pl	SKI13	Pl	TEL11	Sxw		
MOR4	Pl	SKI15	Sxw	TEL12	Pl		
MOR5	Pl	SKI18	Pl, Sxw	TEL13	Pl, Sxw		
MOR6	Sxw	SMI1	Pl	TEL14	Pl, Sxw		
MOR7	Pl	SMI2	Pl	TEL15	Sxw		
MOR8	Pl, Sxw	SMI4	Pl	TEL17	Pl		
MOR9	Pl	SMI7	Pl	TEL18	Pl		
MOR10	Pl	SMI8	Pl	WQ1	Pl		
MOR11	Sxw	SMI11	Sxw	WQ2	Pl		
MOR12	Sxw	SMI13	Pl	WQ3	Pl		
MOR14	Sxw	SMI14	Sxw	WQ4	Pl		
MOR15	Pl, Sxw	SMI16	Sxw	WQ5	Pl		
MOR16	Sxw	SMI18	Sxw	WQ6	Pl		
MOR17	Pl, Sxw	SMI19	Sxw	WQ7	Pl		
MOR18	Pl, Sxw	SMI20	Sxw	WQ8	Pl		
MOR19	Sxw	SMI21	Pl, Sxw	WQ9	Pl		
MOR20	Sxw	SMI22	Pl, Sxw	WQ10	Pl		
MOR21	Sxw	SMI23	Pl, Sxw	WQ11	Pl		
MOR22	Pl, Sxw	SMI24	Pl	WQ12	Pl		
MOR23	Pl	SMI25	Sxw	WQ13	Pl		
MOR25	Sxw	SMI26	Pl, Sxw	WQ14	Pl		
MOR26	Sxw	SMI27	Pl, Sxw	WQ15	Pl		
MOR27	Sxw	SMI28	Pl	WQ16	Pl		
MOR28	Sxw	SMI29	Pl, Sxw	WQ17	Pl		
MOR29	Sxw	SMI30	Sxw	WQ18	Pl		
MOR31	Sxw	SMI31	Pl	WG58	Sxw		
MOR32	Sxw	SMI32	Sxw	WG59	Sxw		
OVEN1	Pl, Sxw	SMI33	Sxw	WG60	Sxw		
OVEN3	Pl	SMI34	Pl	WG61	Sxw		
OVEN4	Pl	SMI35	Sxw	WG62	Sxw		
OVEN5	Pl	SMI36	Pl	WG63	Sxw		
OVEN6	Pl	SMI361	Pl, Sxw	WG64	Sxw		
OVEN8	Pl	SMI37	Pl	WG65	Sxw		
OVEN9	Pl	SMI38	Pl, Sxw	WG66	Sxw		
OVEN10	Pl	SMI39	Pl	WG67	Sxw		
OVEN11	Pl	SMI40	Pl, Sxw	WG68	Sxw		

APPENDIX 2. Breast-height age (bha), site index (SI, metres of 50 yr bha), biogeoclimatic subzone (BGCS), soil moisture regime (SMR), and soil nutrient regime (SNR) for lodgepole pine stands studied. Abbreviations for SMRs and SNRs are explained in Tables 3 and 4, respectively.

Stand	bha	SI	BGCS	SMR	SNR
BUR3	102	12.7	SBSdk	F	VP
BUR5	91	12.5	SBSdk	MD	VP
BUR6	92	12.0	SBSdk	MD	VP
BUR7	93	18.0	SBSdk	VM	P
EQU1	39	20.8	SBSdk	F	M
EQU6	94	11.8	SBSmc	VM	P
EQU7	93	11.4	SBSmc	VM	VP
EQU9	154	10.5	SBSmc	MD	VP
MOR10	86	13.0	SBSdk	MD	VP
MOR15	114	22.8	SBSdk	F	R
MOR17	112	19.0	SBSdk	SD	M
MOR18	126	22.8	SBSdk	F	R
MOR22	122	20.4	SBSdk	SD	R
MOR23	96	17.5	SBSdk	MD	M
MOR3	95	19.3	SBSdk	SD	M
MOR4	92	22.4	SBSdk	F	R
MOR5	95	18.2	SBSdk	SD	M
MOR7	106	17.1	SBSdk	MD	M
MOR8	82	24.8	SBSdk	F	VR
MOR9	85	23.5	SBSdk	F	R
OVEN1	47	18.2	SBSdk	SD	P
OVEN10	48	18.9	SBSdk	F	M
OVEN11	46	18.1	SBSdk	VM	M
OVEN12	48	17.7	SBSdk	SD	P
OVEN3	39	21.1	SBSdk	F	M
OVEN4	47	18.0	SBSdk	SD	P
OVEN5	47	14.0	SBSdk	MD	P
OVEN6	47	17.8	SBSdk	SD	P
OVEN8	48	16.9	SBSdk	M	P
OVEN9	49	15.5	SBSdk	MD	P
SKI10	45	17.9	SBSmc	SD	M
SKI11	85	16.7	SBSmc	MD	M
SKI12	98	18.2	SBSmc	MD	M
SKI13	46	17.7	SBSmc	SD	M
SKI19	40	20.6	SBSmc	F	R
SKI3	84	19.5	SBSmc	VM	R
SKI4	54	17.0	SBSmc	SD	P
SKI5	81	17.9	SBSmc	SD	M
SKI6	82	20.5	SBSmc	F	M
SKI7	132	9.8	SBSmc	VD	P
SKI8	50	20.9	SBSmc	F	M
SKI9	49	21.0	SBSmc	VM	M
SMI1	87	11.1	SBSdk	VM	VP
SMI13	55	15.8	SBSmc	MD	P
SMI2	72	17.3	SBSdk	M	P
SMI21	99	20.3	SBSmc	F	M
SMI22	105	19.7	SBSmc	SD	R
SMI23	89	20.4	SBSmc	F	R
SMI24	94	22.7	SBSmc	M	R
SMI26	99	22.6	SBSmc	M	R
SMI27	104	20.7	SBSmc	M	R
SMI28	100	17.2	SBSmc	MD	P
SMI29	102	21.5	SBSmc	F	M
SMI31	99	17.3	SBSmc	MD	M
SMI34	101	21.6	SBSmc	M	R
SMI36	99	18.5	SBSmc	VD	M
SMI361	91	22.4	SBSmc	F	M
SMI37	96	19.9	SBSmc	SD	M
SMI38	94	16.3	SBSmc	VM	P
SMI39	81	16.5	SBSmc	SD	P

APPENDIX 2. Continued

Stand	bha	SI	BGCS	SMR	SNR
SM4	60	173	SBSdk	SD	P
SM40	56	195	SBSmc	M	M
SM44	65	89	SBSmc	VW	P
SM46	67	202	SBSmc	M	R
SM47	71	182	SBSmc	VM	M
SM7	54	168	SBSdk	SD	P
SM8	52	148	SBSdk	SD	VP
TEL12	50	203	SBSdk	F	M
TEL13	49	178	SBSdk	MD	M
TEL14	47	167	SBSdk	MD	P
TEL17	66	162	SBSdk	MD	P
TEL18	33	169	SBSdk	MD	P
TEL2	49	211	SBSdk	F	M
TEL3	44	191	SBSdk	SD	M
TEL7	106	153	SBSdk	VM	P
WQ1	26	173	SBSmc	SD	P
WQ10	48	179	SBSmc	F	R
WQ11	50	179	SBSmc	F	R
WQ12	51	169	SBSmc	SD	P
WQ13	52	166	SBSmc	SD	P
WQ14	53	204	SBSmc	F	R
WQ15	48	137	SBSmc	W	R
WQ16	52	209	SBSmc	M	R
WQ17	50	194	SBSmc	VM	R
WQ18	25	156	SBSmc	MD	P
WQ2	26	167	SBSmc	W	VR
WQ3	26	186	SBSmc	SD	P
WQ4	46	217	SBSmc	VM	R
WQ5	46	210	SBSmc	F	R
WQ6	26	187	SBSmc	SD	M
WQ7	48	192	SBSmc	VM	VR
WQ8	27	171	SBSmc	SD	P
WQ9	26	184	SBSmc	M	R

APPENDIX 3. Breast height age (bha), site index (SI, metres at 50 yr bha), biogeoclimatic subzone (BGCS), soil moisture regime (SMR), and soil nutrient regime (SNR) for interior spruce stands studied. Abbreviations for SMRs and SNRs are explained in Tables 3 and 4, respectively.

Stand	bha	SI	BGCS	SMR	SNR
BLR7	92	15.0	SBSdk	VM	P
EQU1	45	18.8	SBSdk	F	M
EQU2	69	9.6	SBSdk	VD	P
EQU4	76	19.2	SBSdk	F	R
MOR1	93	21.4	SBSdk	F	R
MOR11	92	19.3	SBSdk	F	M
MOR12	99	22.9	SBSdk	VM	R
MOR14	120	6.3	SBSdk	VD	VP
MOR15	123	18.6	SBSdk	F	R
MOR16	133	18.7	SBSdk	VM	M
MOR17	108	17.4	SBSdk	SD	M
MOR18	104	20.0	SBSdk	F	R
MOR19	110	24.5	SBSdk	F	VR
MOR2	84	17.2	SBSdk	SD	P
MOR20	98	23.4	SBSdk	F	R
MOR21	125	22.8	SBSdk	VM	VR
MOR22	110	16.7	SBSdk	SD	R
MOR25	100	12.1	SBSmc	MD	P
MOR26	97	8.0	SBSmc	VD	P
MOR27	98	11.5	SBSmc	MD	P
MOR28	94	13.6	SBSmc	SD	P
MOR29	49	16.9	SBSmc	M	M
MOR31	52	19.1	SBSmc	M	R
MOR32	52	19.1	SBSmc	F	R
MOR6	42	24.5	SBSdk	F	VR
MOR8	72	25.4	SBSdk	F	VR
OVEM1	43	17.3	SBSdk	SD	P
SKI15	140	4.3	SBSmc	VW	R
SKI18	51	19.0	SBSmc	F	R
SKI2	83	15.7	SBSmc	W	R
SKI3	82	19.3	SBSmc	VM	R
SMI11	84	17.3	SBSmc	VM	VR
SMI14	44	19.8	SBSmc	SD	R
SMI16	105	18.6	SBSmc	F	M
SMI18	93	13.8	SBSmc	MD	M
SMI19	79	22.1	SBSmc	M	VR
SMI20	44	23.9	SBSmc	F	VR
SMI21	86	17.7	SBSmc	F	M
SMI22	80	19.9	SBSmc	SD	R
SMI23	87	19.4	SBSmc	F	R
SMI25	86	20.8	SBSmc	VM	R
SMI26	93	18.8	SBSmc	M	R
SMI27	81	20.4	SBSmc	M	R
SMI29	77	17.3	SBSmc	F	M
SMI30	47	19.6	SBSmc	M	R
SMI32	70	20.3	SBSmc	M	R
SMI33	92	18.0	SBSmc	F	R
SMI35	104	17.9	SBSmc	VM	R
SMI361	103	15.9	SBSmc	F	M
SMI38	92	12.3	SBSmc	VM	P
SMI40	50	18.2	SBSmc	M	M
SMI48	107	13.7	SBSmc	MD	M
TEL1	44	21.3	SBSdk	F	R
TEL10	51	16.3	SBSdk	MD	M
TEL11	51	18.8	SBSdk	SD	M
TEL13	45	14.5	SBSdk	MD	M
TEL14	49	13.2	SBSdk	MD	P
TEL15	47	22.2	SBSdk	F	R
TEL3	40	16.3	SBSdk	SD	M
TEL4	41	22.1	SBSdk	F	R

APPENDIX 3. Continued

Stand	bha	SI	BGCS	SMR	SNR
TEL8	45	16 7	9BSdk	F	M
TEL9	49	14 5	SBSdk	MD	M
WG58	95	18 3	SBSdk	SD	R
WG59	91	15 0	SBSdk	MD	M
WG60	83	14 5	SBSdk	MD	M
WG61	48	21 5	SBSdk	VM	R
WG62	53	20 0	SBSdk	SD	R
WG63	63	17 0	SBSdk	SD	M
WG64	52	16 5	SBSdk	MD	M
WG65	34	6 0	SBSdk	W	VP
WG66	51	19 3	SBSdk	SD	R
WG67	54	19 3	SBSdk	SD	M
WG68	55	14 7	SBSdk	SD	P
WG69	49	20 5	SBSdk	SD	R
WG70	84	19 9	SBSdk	F	R
WG71	47	17 0	SBSdk	MD	P
WG72	46	22 6	SBSdk	F	VR

APPENDIX 4. Number of stands and means and standard deviations (in parentheses) of site index (metres at 50 yr bha) of the 93 lodgepole pine stands studied, stratified by soil moisture and nutrient regimes

Soil moisture regime	Soil nutrient regime				
	Very poor	Poor	Medium	Rich	Very rich
Very dry		9.8 n=1	18.5 n=1		
Moderately dry	12.0 (0.9) n=4	15.9 (0.9) n=8	17.4 (0.5) n=6		
Slightly dry	14.8 n=1	17.4 (0.6) n=13	18.6 (0.7) n=9	20.1 (0.3) n=2	
Fresh	12.7 n=1		20.8 (0.9) n=10	21.3 (2.0) n=10	24.8 n=1
Moist		17.11 (0.2) n=2	19.5 n=1	21.0 (1.4) n=7	
Very moist	11.3 (0.1) n=2	15.3 (2.2) n=4	19.1 (1.6) n=3	20.2 (1.1) n=3	19.2 n=1
Wet				13.7 n=1	16.7 n=1
Very wet		8.9 n=1			

APPENDIX 5. Number of stands, and means and standard deviations (in parentheses) of site index (metres at 50 yr bha) of the 77 interior spruce stands studied, stratified by soil moisture and soil nutrient regimes

Soil moisture regime	Soil nutrient regime				
	Very poor	Poor	Medium	Rich	Very rich
Very dry	6.3 n=1	8.8 (1.1) n=2			
Moderately dry		13.5 (2.5) n=4	14.9 (1.0) n=8		
Slightly dry		15.7 (1.8) n=4	17.8 (1.2) n=5	19.2 (1.2) n=7	
Fresh			17.8 (1.2) n=7	20.3 (1.6) n=13	24.2 (1.0) n=5
Moist			18.6 (0.5) n=2	19.6 (0.7) n=5	22.1 n=1
Very moist		13.7 (1.9) n=2	18.7 n=1	20.3 (2.1) n=5	20.1 (3.9) n=2
Wet	6.0 n=1			15.7 n=1	
Very wet				4.3 n=1	

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